Final Scientific and Technical Report for Grant DE-FG02-99ER41099 Entitled "Study the Collective Behavior of Quarks and Gluons in High Energy Nuclear Collisions"

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Executive Summary

Grant DE-FG02-99ER41099 supported scientific work on the PHOBOS experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC). PHOBOS was an experiment that examined in detail energetic collisions between nuclei. The PHOBOS experiment was one of four experiments that took place in the early stages of the RHIC program. The four experiments – STAR, PHENIX, BRAHMS, and PHOBOS - were complementary. BRAHMS and PHOBOS have completed their experimental programs while STAR and PHENIX continue to take data. The intent of the overall project was to study the nature of nuclear matter and the forces that govern nuclear matter at very high energies and temperatures. The experiments have been a great success scientifically, uncovering some surprises about the nature of nuclear matter and establishing the existence of a new state of matter called the strongly interacting quark-gluon plasma. By understanding better the nature of nuclear matter under these conditions, we test our fundamental picture of the strong nuclear force and learn things that may help us understand the early universe and extreme astrophysical processes.

Comparison of accomplishments with actual goals of project

The PHOBOS experiment exceeded the goals and expectations. The work done by the group supported through this grant also exceeded goals and expectations. Initially PHOBOS was expected to make good measurements of the overall multiplicity of particles produced in the collision and to look for unusual events. PHOBOS did this. In addition, PHOBOS was able to look at global patterns in the particle production in order to infer information about the collective flow of particles in the initial state of the collision (so-called collective flow). This work was initially done by the Rochester group and it opened up a series of investigations involving flow that were important to the RHIC program. The flow program of PHOBOS was something of a surprise to most of the RHIC community.

Summary of project activities

The scientific work and methodology of the Rochester group and PHOBOS experiment are well-documented in the numerous papers listed at the back of this report. These documents are published and openly available.

The project activities of the Rochester group on PHOBOS can be summarized as follows:

- Our group first learned to look at the patterns of energy deposition in different parts of the PHOBOS detector to measure collective flow in Au-Au collisions. We discovered that the magnitude of the collective flow drops as you move away from mid-rapidity. Initially this was a surprise as people expected measurements to stay constant over a large range of rapidity (boost invariance). This was the first example of a measurement at RHIC that showed clearly that boost invariance did not hold.

- Our group compared the collective flow signals in Au-Au collisions at four different energies and established that the signals were qualitatively similar. We found evidence that the flow evolves similarly toward mid-rapidity in the frame of reference of one of the incoming nuclei. We called this phenomenon extended longitudinal scaling.

- Our group measured the collective flow in collisions of Cu nuclei and found the behavior of flow to be qualitatively similar to that in the Au-Au collisions.

- We discovered that attempts to scale the signals with the overlap eccentricity in the collisions in order to compare the flow signals for Cu-Cu and Au-Au did not work well using the standard eccentricity definition. PHOBOS proposed a new definition for eccentricity, called the participant eccentricity, which varies with fluctuating positions of participating nucleons. The Au and Cu flow results were found to be very similar when scaled by this new eccentricity. This new definition has now been widely accepted in the RHIC community.

- Our group measured both the first and second moment of the collective flow in Au-Au collisions at different energies.

- We developed algorithms to align the silicon elements of the PHOBOS spectrometer and used these algorithms to help determine the alignment for periods of data-taking.

- We studied energy deposition patterns in the PHOBOS multiplicity detector to see if it is possible to identify collisions with anomalous strange particle production. The idea was to look at the average energy deposition of particles at large rapidity as compared to that at mid-rapidity. Particle containing strange quarks are expected to give a slightly higher energy deposition at mid-rapidity. A search of the data using this technique did not uncover any evidence of events with highly anomalous strange particle production.

- Our group participated in (and chaired some of) the internal review processes for physics papers in PHOBOS for many different analyses, including low-pt particle production, flow papers, flow fluctuations papers, and a search for strange event topologies.

- One master's degree was awarded to a Rochester student working on this project – Adam Harrington (2004) "Limiting fragmentation in collective flow measurements in gold-gold collisions at 19.6, 130, and 200 GeV per nucleon pair"

- One Ph.D. was awarded to a Rochester student working on this project – Joshua Hamblen (2006) "Pseudorapidity dependence of directed and elliptic flow in Au+Au collisions at 19.6, 62.4, 130, and 200 GeV per nucleon pair"

- We expect to award one more Ph.D. to a Rochester student on this project – Peter Walters (expected 2008-2009)

Products of the project

The primary products of this project are the PHOBOS detector and scientific and technical publications describing the detector and the physics analyses. The PHOBOS website is http://www.phobos.bnl.gov/ . The publications and presentations given by members of the PHOBOS collaboration can be found on this website as well as in the relevant journal or conference website. In addition, the complete list of collaborators can be found on the website and in the papers. The PHOBOS detector is described in Nucl. Inst. Meth. A499, 603 (2003).

The PHOBOS experiment generated large amounts of data taken during different run conditions at RHIC. This data resides at Brookhaven National Laboratory. The physicists of the PHOBOS experiment developed large software packages to analyze the data. These packages evolved with time during the course of the experiment and are scattered between BNL and computers in the collaborating institutions. The basic algorithms used to analyze the data are well described in the scientific and technical publications of PHOBOS.

Computer modeling

By virtue of the nature of how heavy ion physics is done, the PHOBOS experiment made (makes) use of many different computer simulation packages. We use an event generator to create simulated heavy ion collisions. Usually we use code called HIJING for this purpose (references given in our papers). But, we also use other generators as well. We simulate our detector and the interactions of the particles in our detector using a package call GEANT. Again, the version of the program changed through the course of the experiment and the references are given in our papers. Finally, we used many smaller Monte Carlo programs to evaluate many aspects of each analysis. These algorithms are described in our scientific publications.

Publications

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